CRATER COMPARISONS

Investigating Impact Craters on Earth and Other Planetary Worlds

Teacher Guide

Goal: This activity is designed to introduce students to the process of science through the completion of a structured mini-research investigation focusing on impact craters on Earth and planetary worlds in our Solar System.

Objectives: Students will:

1. Identify the causes and formation of impact craters
2. Identify characteristics of impact craters
3. Compare and contrast characteristics of impact craters
4. Carry out a mini-research investigation by modeling the process of science and completing the following steps:
    1) Asking preliminary questions
    2) Making initial observations
    3) Applying background knowledge
    4) Implementing an experiment design to answer a specific scientific question
    5) Collecting and compiling data
    6) Displaying data
    7) Analyzing and interpreting data
    8) Drawing conclusions and considering potential implications of research

Grade Level: 6 – 8*

***Grade Level Adaptations:** This activity may also be applicable for students in grades 5 and 9-12. Students in grades 9-12 should be able to work through the activity more independently than younger grade level students. For younger students it is recommended to check for comprehension of each section as students step through this research process.

Time Requirements: This activity can be completed in 8-10 class periods. Class periods are based on a 45-minute session.

Below are estimated time requirements for each section of the activity:

- PART 1: IDENTIFYING CRATER CHARACTERISTICS: ~20 minutes
- PART 2: EXPLORING IMPACT CRATERS AND MAKING INITIAL OBSERVATIONS: ~1-2 class periods
- PART 3: CONTINUING OUR CRATER INVESTIGATION: ~6-7 class periods
- PART 4: EVALUATE: ~20-30 minutes

(Procedures for each part of this activity are included in the ACTIVITY PROCEDURE Section of this guide.)

Materials:

- *CRATER COMPARISONS Student Guide*
- Data Collection Table (Earth) Handout
- Data Collection Table (Planetary) Handout
- Earth Impact Crater Images (1 set per group)
- Planetary Impact Crater Images (1 set per group) [NOTE: You can decide to focus on 1 planetary body or multiple planetary bodies, as desired. Image sets provided for this activity include images of Earth's Moon, Mars, Vesta (an asteroid), Mercury, and Venus.]
- Crater Image Metadata Handout
- Crater Comparison Assessment
- Computers (optional)
- Information on planetary worlds being investigated (either through lithographs, books, or posters you may have or through the use of the Useful Websites listed below.)

STANDARDS ALIGNMENT

National Science Education Standards:

CONTENT STANDARD A: Science as Inquiry
CONTENT STANDARD D: Earth and Space Science
CONTENT STANDARD G: History and Nature of Science

Next Generation Science Standards:

Disciplinary Core Idea

- ESS1C. History of Planet Earth

Science and Engineering Practices

- Practice 1: Asking Questions and Defining Problems
- Practice 3: Planning and Carrying Out Investigations
- Practice 4: Analyzing and Interpreting Data
- Practice 5: Using Mathematics and Computational Thinking
- Practice 6: Constructing Explanations and Designing Solutions
- Practice 7: Engaging in Argument from Evidence
- Practice 8: Obtaining, Evaluating, and Communicating Information

Cross Cutting Concepts

- 1. Patterns
- 2. Cause and Effect
- 3. Scale, Proportion, and Quantity
- 6. Structure and Function
- 7. Stability and Change

Nature of Science

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural System
- Science is a Human Endeavor
- Science Addresses Questions about the Natural and Material World

TEACHER OVERVIEW AND INTRODUCTION:
To effectively prepare the nation's future Science Technology Engineering and Mathematics (STEM) workforce, students in today's classrooms need opportunities to engage in authentic experiences that model skills and practices used by STEM professionals. Relevant, real-world authentic research experiences allow students to behave as scientists as they model the process of science. This enables students to get a true sense of STEM-related professions and also allows them to develop the requisite knowledge, skills, curiosity, and creativity necessary for success in STEM careers. The importance of these skills is evident in the restructuring of science education standards into the Next Generation Science Standards. These standards require K-12 science educators to infuse activities into their standard curriculum that allow students to experience science and engineering practices.

This activity addresses the Next Generation Science Standards while recognizing students potentially lack experience with scientific practices involved in conducting research. This inexperience may lead to challenges facilitating research in the classroom, or lead to a less than successful or incomplete research experience for students. This activity is designed as an entry level research engagement activity that introduces, illustrates, and teaches the skills involved in each step of the scientific research process. Students actively participate in each step of the process of science as they complete a structured comparative planetology research investigation. Students begin the activity by making observations of impact craters found on different planetary worlds. As students continue with the activity they gain knowledge in the causes and formation of impact craters and learn to identify characteristics of these features. Students then make observations of these characteristics as they gather, display, analyze, and interpret data to carry out the structured research activity.

Parts 1 and 2 of the activity introduce students to Steps 1-3 of the process of science and help lay the foundation that will allow them to complete the remaining aspects of the investigation. Part 3 of the activity begins by setting up the experimental design (methods) and guides students through Steps 4-8 of the process of science to enable them to complete the research. Part 3 ends by having students think about the overall implications of this research. Though not explicitly included in this activity, Step 9 in the process of science focuses on sharing research. Consider having your students present their research to your principal, school board, parents, or other students to demonstrate their knowledge and experience modeling the skills and practices of STEM professionals through their planetary research conducted in the classroom. Part 4 of the activity is a Crater Comparison Assessment. This assessment will allow you to evaluate student achievement of the objectives of this activity.

By helping students model the process of science using this activity, they can gain experience modeling the skills and practices used by actual scientists and think more critically when conducting a future investigation.

Addressing the Challenges of Research in the Classroom

Some of the challenges of conducting research in the classroom can be in how to help students formulate an answerable research question during a reasonable amount of class time, how to organize their research, how to engage the entire class in the same research activity, and how to make sure students will be able to obtain the data they need to successfully complete their research. This activity addresses these potential challenges by providing structured suggestions and providing the necessary resources to complete this investigation. Images/data include Crew Earth Observation (CEO) imagery of Earth acquired by astronauts on the International Space Station or Space Shuttle as well as remote sensing data acquired by robotic spacecraft exploring other worlds in our Solar System.

Connection to NASA's Expedition Earth and Beyond Program

This activity is designed as part of NASA's Expedition Earth and Beyond (EEAB) program (http://ares.jsc.nasa.gov/ares/eeab/). EEAB aims to actively involve students in NASA exploration, discovery, and the process of science. The process of science structure used for this activity is based on the Expedition Earth and Beyond (EEAB) Student Scientist Guidebook. Many of the images used for this activity come from other EEAB activities such as the Blue Marble Matches activity (http://ares.jsc.nasa.gov/ares/eeab/BMM.cfm). Images have been reformatted and additional information has been provided specifically to assist students with the research conducted through this activity.

Benefits of Extending Research in the Classroom

The Expedition Earth and Beyond Program encourages teachers to have their students expand on this *Crater Comparison* research investigation or initiate their own unique investigation. Through these extensions of research in the classroom, students have the opportunity to benefit from two unique and powerful resources:

- **Access to a mentor:** Students expanding on this research or initiating a new research investigation have the opportunity to work with a mentor. Mentors are STEM professionals who can provide helpful tips and input to students as they progress through their research.
- **Requesting new CEO data from astronauts on the ISS:** To support student research, students can request new Crew Earth Observation (CEO) data to be obtained by astronauts on the International Space Station (ISS). Image requests can be submitted by completing a *Data Request Form*. *Data Request Forms* are available at: http://ares.jsc.nasa.gov/ares/eeab/documents/EEAB_DataRequestForm.pdf. (Limit 1 Data Request Form per class.)

Useful Websites:

- Expedition Earth and Beyond Program: http://ares.jsc.nasa.gov/ares/eeab/
- Gateway to Astronaut Photography of Earth: http://eol.jsc.nasa.gov
- Planetary Photojournal: http://photojournal.jpl.nasa.gov
- Earth Impact Database: http://www.passc.net/EarthImpactDatabase/index.html
- Google Earth, Moon, and Mars: http://earth.google.com; http://www.google.com/moon/ http://www.google.com/mars/ [Other maps may be available.]
- Solar System Exploration: http://solarsystem.nasa.gov/planets/

- Exploring the Planets: http://nasm.si.edu/etp
- Impact Cratering: http://www.lpi.usra.edu/education/explore/shaping_the_planets/impact_cratering.shtml

Extensions:

1. You may want to have your students complete a more in-depth investigation focusing on craters on Earth. Students can look for additional craters to investigate using the Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html). This database provides information such as the location of impact craters on Earth, their estimated ages, diameters, and access to different types of imagery/data to observe these craters. Students should also consider looking for Crew Earth Observation data of impact craters by going to the Gateway to Astronaut Imagery of Earth (http://eol.jsc.nasa.gov) and searching for visible imagery of these impact craters. There are numerous ways to search for imagery, but students may want to search using the Google Map tool on this website (http://eol.jsc.nasa.gov/scripts/SSEOP/GoogleMapsQuery.pl). Imagery of some craters may not be available.
2. You may wish to have your students complete a more in-depth investigation gathering additional data from each planetary world they have investigated during this activity.
3. You could have students design an investigation focusing on Earth or planetary comparisons using this investigation as a model.
4. Have students design a mission to visit one of these planetary worlds.

5-E Model of Inquiry: This activity is designed using the 5-E model of inquiry. This model of instruction is based on a constructive approach to learning where students learn by building or constructing new ideas by comparing new experiences to existing frameworks of knowledge. The 5-E model of instruction breaks this approach into 5 phases:

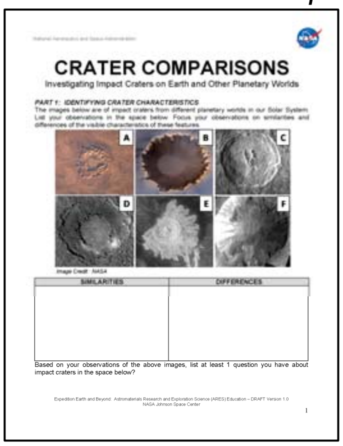
5-E Phase	General Description	Crater Comparison Activity
Engage	Teachers engage students using an activity, image, or discussion to focus students' thinking on the learning outcomes of an activity.	Students observe images and list similarities and differences of visible characteristics of impact craters. (Part 1)
Explore	Students actively explore and make discoveries using hands-on materials. Students develop concepts, processes, and skills to establish an understanding of content.	Students read background information and explore images of Earth and other planetary worlds to gather data, log observations, and build their knowledge and understanding of impact craters. (Parts 2 & 3)
Explain	Students communicate and explain concepts they have been exploring. Students use formal language and vocabulary associated with content.	Students use created data displays and listed observations to help them analyze and interpret data. Students share their findings with the class. (Part 3)
Elaborate	Students extend conceptual understandings to new problems or experiences. Students reinforce and develop a deeper understanding of concepts and skills.	Students apply knowledge acquired to draw conclusions about their research and consider the potential implications in the "What Does It All Mean" section of the *Student Guide*. (Last 2 sections of Part 3)
Evaluate	Teachers and students assess new knowledge and understanding of key concepts.	Students complete the Crater Comparison Assessment. (Part 4)

ACTIVITY PROCEDURE:

This set of activity procedures is provided as a suggested guide for the *Crater Comparison* classroom activity. Estimated time frames for each section are provided but can vary depending on your level of students and time you feel is necessary for classroom discussions.

PART 1: IDENTIFYING CRATER CHARACTERISTICS (**E**ngage)
Estimated time for Part 1: *~20 minutes*
Materials Needed:

- *Student Guide page 1*

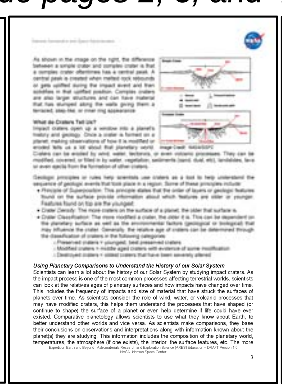
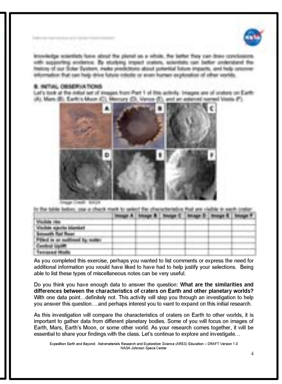

CRATER COMPARISONS
Investigating Impact Craters on Earth and Other Planetary Worlds
SIMILARITIES | DIFFERENCES
Based on your observations of the above images, list at least 1 question you have about impact craters in the space below?

This part of the activity is designed to engage students by having them make observations of impact craters from different planetary worlds in our Solar System. It can also serve as a way to determine prior knowledge students may have about impact craters.

1. Divide the class into groups consisting of ~4 students
2. Have students follow the instructions provided on page 1 of the *Student Guide.* Students are asked to list similarities and differences of the visible characteristics they can observe of the provided impact crater images. Give students ~12-15 minutes to list their observations.
3. Ask students to formulate a question they have about impact craters based on their observations of the provided images. Students should write their questions at the bottom of the page.
4. Briefly discuss student observations and questions. As students share their questions, validate that all questions are good questions. You may also ask students to consider what type of data they would need to answer their question. This activity will help reinforce how when asking a research question you need to have a plan in which to obtain the necessary data to answer that question with supporting evidence.

PART 2: EXPLORING IMPACT CRATERS AND MAKING INITIAL OBSERVATIONS (**E**xplore)
Estimated time for Part 2: *~1-2 class periods*
Materials Needed:

- *Student Guide pages 2, 3, and 4.*

Based on student group discussions and the observations they list in Part 1, you will have an idea what students may already be familiar with related to impact craters. This part of the activity can help clear up any potential misconceptions or misinformation students may have and provide background information ensuring all students have a baseline of similar background knowledge. The last section of the background information (*Using Planetary Comparisons to Understand the History of our Solar System*) will be important as students think about the potential implications of their research in the last section of this activity.

A. BACKGROUND INFORMATION: The *Background Information* section is divided into five sub-sections of information. Assign a sub-section to different groups of students so they can become responsible to share the information they read with the rest of the class. Students should be prepared to give a summary of the information they have read. The questions listed below may help students pull out important summary information. Alternatively, you may want to ask students to independently read each section (in class or for homework) and answer the questions provided below. Sections and summary questions include:

a) Causes of Impacts
   - How are impact craters created?
   - What is the difference between a meteoroid, meteor, and meteorite?
   - Where do we find impact craters?
   - What is the most common process seen across the Solar System?

b) Formation of Craters
   - Briefly describe the following stages of crater formation:
     - Contact/Compression Stage:
     - Excavation Stage:
     - Modification Stage:
   - Once a crater is formed, what forces or processes can modify the crater?
   - How long does the crater formation process take?

c) Crater Characteristics
   - Identify the 5 main parts or characteristics of a crater.
   - Describe two differences between a simple crater and complex crater.
   - Describe how a central peak forms.

d) What do Craters Tell Us?
   - What types of processes can modify a crater?
   - What types of materials may modify, cover or fill in a crater?
   - Briefly describe the following geologic principles or rules:
     - Principle of Superposition
     - Crater Density
     - Crater Classifications

e) Using Planetary Comparisons to Understand the History of our Solar System
   - What is the name of the type of science that allows scientists to use what they know about Earth to better understand other worlds in our Solar System and vice versa?
   - When making comparisons about planetary worlds what do scientists use to base their conclusions?
   - When studying a planetary world, what detailed information can be helpful to know?
   - Why is it useful to study impact craters?

Discuss the background information and summary questions with students as necessary to ensure all students understand the information they have read.

B. INITIAL OBSERVATIONS: Following the discussion of the background information, in the table provided have students log initial observations of specific characteristics visible in the crater images. After students log their observations, ask them the following questions:

a) Did you want to make comments about some of the observations you were logging as opposed to just putting in a check mark? (Hopefully students will say yes to this, reinforcing the idea that sometimes it is important to state some miscellaneous notes about your observations.)
b) Can you now answer the following question: What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds? (Hopefully students will realize that with one data point they may be able to have an idea as to the similarities and differences, but with more data, they can better answer this question.)

PART 3: CONTINUING OUR CRATER INVESTIGATION (**E**xplore and **E**xplain)

Estimated time for Part 3: *~6-7 class periods [Each step of the process of science included in Part 3 (Steps 4 – 8) is explained below. Explanation includes a breakdown of materials needed and an estimated time for the completion of that step.]*

Materials Needed:

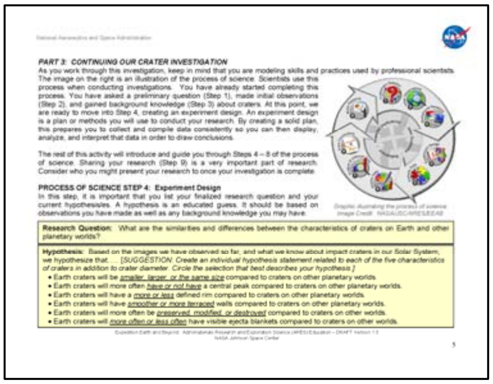
- *Student Guide pages 5 – 18 (thumbnail images of pages are provided with the description of each section)*
- Data Collection Table (Earth) Handout
- Data Collection Table (Planetary) Handout
- Earth Impact Crater Images (1 set per group)
- Planetary Impact Crater Images (1 set per group) [NOTE: You can decide to focus on 1 planetary body or multiple planetary bodies, as desired. Image sets provided for this activity include images of Earth's Moon, Mars, Vesta, Mercury, and Venus.]
- Crater Image Metadata Handout

[The listed handouts and image resources are available at the end of this *Teacher Guide*.]

This part of the activity is designed to provide students with experience in the remaining steps of the process of science. They have already completed Steps 1 – 3 during Parts 1 and 2 of the activity. Part 3 will introduce and guide students through Steps 4 – 8 including: Experiment Design (Step 4), Collect and Compile Data (Step 5), Display Data (Step 6), Analyze and Interpret Data (Step 7), and Drawing Conclusions (Step 8). Though it is not a formal part of this activity, Sharing Research (Step 9) is an important part of the process of science. If you have the opportunity we encourage you to have your students present their research to an administrator, school board, parents, or other suitable audiences.

STEP 4: EXPERIMENT DESIGN (~20-30 minutes)
Materials Needed for Step 4:

- *Student Guide pages 5 – 6*



PART 3: CONTINUING OUR CRATER INVESTIGATION
As you work through this investigation, keep in mind that you are modeling skills and practices used by professional scientists. The image on the right is an illustration of the process of science. Scientists use this process when conducting investigations. You have already started completing this process. You have asked a preliminary question (Step 1), made initial observations (Step 2), and gained background knowledge (Step 3) about craters. At this point, we are ready to move into Step 4, creating an experiment design. An experiment design is a plan or methods you will use to conduct your research. By creating a solid plan, this prepares you to collect and compile data consistently so you can then display, analyze, and interpret that data in order to draw conclusions.

The rest of this activity will introduce and guide you through Steps 4 – 8 of the process of science. Sharing your research (Step 9) is a very important part of research. Consider who you might present your research to once your investigation is complete.

PROCESS OF SCIENCE STEP 4: Experiment Design
In this step, it is important that you list your finalized research question and your current hypothesis/es. A hypothesis is an educated guess. It should be based on observations you have made as well as any background knowledge you may have.

Graphic illustrating the process of science. Image Credit: NASA/JSC/ARES/EEAB

Research Question: What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?

Hypothesis: Based on the images we have observed so far, and what we know about impact craters in our Solar System, we hypothesize that….. [SUGGESTION: Create an individual hypothesis statement related to each of the five characteristics of craters in addition to crater diameter. Circle the selection that best describes your hypothesis.]
- Earth craters will be smaller, larger, or the same size compared to craters on other planetary worlds.
- Earth craters will more often have or not have a central peak compared to craters on other planetary worlds.
- Earth craters will have a more or less defined rim compared to craters on other planetary worlds.
- Earth craters will have smoother or more terraced walls compared to craters on other planetary worlds.
- Earth craters will more often be preserved, modified, or destroyed compared to craters on other worlds.
- Earth craters will more often or less often have visible ejecta blankets compared to craters on other worlds.

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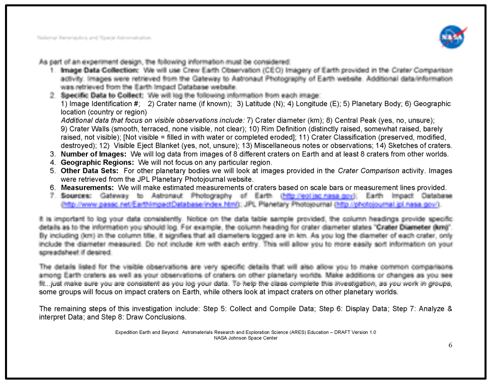

As part of an experiment design, the following information must be considered:
1. **Image Data Collection:** We will use Crew Earth Observation (CEO) Imagery of Earth provided in the *Crater Comparison* activity. Images were retrieved from the Gateway to Astronaut Photography of Earth website. Additional data/information was retrieved from the Earth Impact Database website.
2. **Specific Data to Collect:** We will log the following information from each image:
1) Image Identification #; 2) Crater name (if known); 3) Latitude (N); 4) Longitude (E); 5) Planetary Body; 6) Geographic location (country or region)
Additional data that focus on visible observations include: 7) Crater diameter (km); 8) Central Peak (yes, no, unsure); 9) Crater Walls (smooth, terraced, none visible, not clear); 10) Rim Definition (distinctly raised, somewhat raised, barely raised, not visible); [Not visible = filled in with water or completed eroded]; 11) Crater Classification (preserved, modified, destroyed); 12) Visible Eject Blanket (yes, not, unsure); 13) Miscellaneous notes or observations; 14) Sketches of craters.
3. **Number of Images:** We will log data from images of 8 different craters on Earth and at least 8 craters from other worlds.
4. **Geographic Regions:** We will not focus on any particular region.
5. **Other Data Sets:** For other planetary bodies we will look at images provided in the *Crater Comparison* activity. Images were retrieved from the JPL Planetary Photojournal website.
6. **Measurements:** We will make estimated measurements of craters based on scale bars or measurement lines provided.
7. **Sources:** Gateway to Astronaut Photography of Earth (http://eol.jsc.nasa.gov/); Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html); JPL Planetary Photojournal (http://photojournal.jpl.nasa.gov/).

It is important to log your data consistently. Notice on the data table sample provided, the column headings provide specific details as to the information you should log. For example, the column heading for crater diameter states "**Crater Diameter (km)**". By including (km) in the column title, it signifies that all diameters logged are in km. As you log the diameter of each crater, only include the diameter measured. Do not include km with each entry. This will allow you to more easily sort information on your spreadsheet if desired.

The details listed for the visible observations are very specific details that will also allow you to make common comparisons among Earth craters as well as your observations of craters on other planetary worlds. Make additions or changes as you see fit…just make sure you are consistent as you log your data. To help the class complete this investigation, as you work in groups, some groups will focus on impact craters on Earth, while others look at impact craters on other planetary worlds.

The remaining steps of this investigation include: Step 5: Collect and Compile Data; Step 6: Display Data; Step 7: Analyze & interpret Data; and Step 8: Draw Conclusions.

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OVERVIEW OF THE PROCESS OF SCIENCE:
Let students know that as scientists conduct investigations, they follow what we call the process of science. The graphic on page 5 of the *Student Guide* shows an illustration of that process. Let students know they have already completed Steps 1–3 of this process. Step 1 included their Preliminary Question about impact craters based on their initial observations. Step 3 included their gain of background knowledge about impact craters. Step 2 enabled them to make a set of structured initial and more informed observations about the impact craters. Let students know that even though the Steps shown in the process of science illustration are numbered from 1 – 9, it is very common for scientists to move back and forth among these steps. This is what makes this process a very iterative process. Scientists oftentimes refine their research question as they make initial observations and gain more knowledge about the feature and process they may be investigating. However, once that final research question is defined, a plan needs to be put in place in order to answer that question with supporting evidence. This plan, called the Experiment Design, is part of Step 4 of the process of science. Establishing a research question and developing an appropriate experiment design are critical aspects of any research investigation.

STEP 4: EXPERIMENT DESIGN:
1. QUESTION AND HYPOTHESIS: Let students know that defining an experiment design can be challenging, especially if you have little experience defining a research plan. For starters, students should be sure to list the research question and come up with their hypothesis/es. The example hypotheses in the *Student Guide* suggest that students create a hypothesis statement about 5 characteristics of craters as well as crater diameter. Students should base their hypotheses on what they may already know or observations they have previously made of craters. Too often students believe a hypothesis is just a guess. They should realize that a hypothesis is an educated guess based on what they may already know or what they have observed. The additional research they do, along with specific data they collect, will allow them to determine if their original hypotheses are supported or refuted.

2. EXPERIMENT DESIGN: The plan or experiment design for any research investigation is driven by the research question and hypotheses. This drives the data that will be collected in order to draw conclusions. Review the information listed that needs to be considered in order to complete this investigation. These seven items basically parallel important considerations for any type of research investigation. They include:

1) ***Image Data Collection:*** It is important to know where you will retrieve your data. In this activity, the data (images) have already been organized so students can focus on logging metadata and observations. Finding useful image data can sometimes be very time consuming.
2) ***Specific Data to Collect:*** Students need to think about the specific data they will collect and log from every image observed. It is important to be as consistent (and detailed) as possible with data collection. It can be challenging for students to determine what data to collect, especially if they have little experience conducting research.
3) ***Number of Images*:** Students should consider the number of images or data points they would like to collect. The more data collected, the more evidence they will have to support their conclusions.
4) ***Geographic Region:*** Students should think about whether they will focus on a specific geographic region. Since there is no one specific region in which we find impact craters on Earth, this investigation will not focus on any particular region.
5) ***Other Data Sets:*** It is important for students to know where they will retrieve additional data for their research. In this activity these additional data sets (images of craters on numerous planetary bodies) are provided. Students can expand on this as they wish.
6) ***Measurements*:** If students plan to include measurements in their research, they should be able to indicate how they are going about obtaining those measurements. In this activity either a scale bar or measurement reference line has been included on each available image included as part of the activity.
7) ***Sources:*** Students should list the sources of their data retrieval. This enables others to make observations of the same images included in the research, or look for additional data.

There is certainly a lot to think about when designing a research investigation. For this investigation, the information has been structured and provided to help students gain experience in this aspect of their research. By discussing this information with students, they can reflect on and be better prepared to critically think about these important considerations if they were to design a future research investigation.

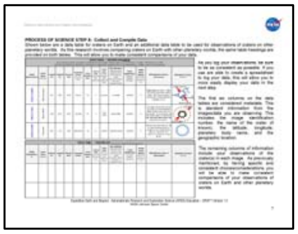
STEP 5: COLLECT AND COMPILE DATA (~1-2 class periods)

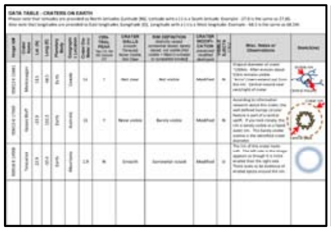
Materials Needed for Step 5:

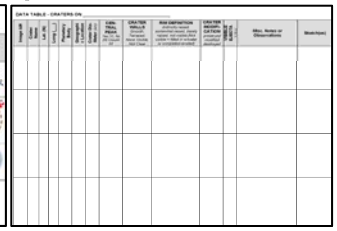
- *Student Guide page 7*
- *Hard copy (and/or spreadsheet of) data collection sheets (Earth or other planetary world)*
- *Crater Image Metadata*
- *Images of impact craters (~8 images per planetary body)*
- *Access to computers (optional)*

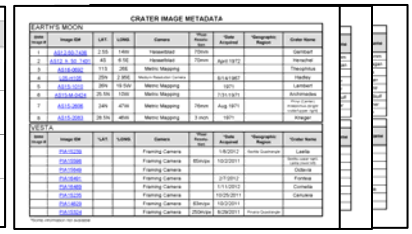
[The listed handouts are available at the end of this *Teacher Guide*.]

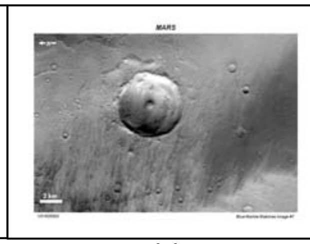
Thumbnail images of materials needed for Step 5: *(Not shown below: Thumbnail image of Mercury and Venus)*

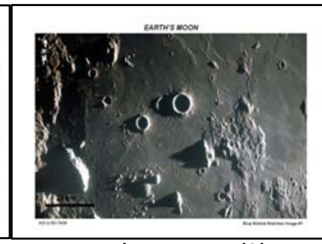

Student Guide page 7

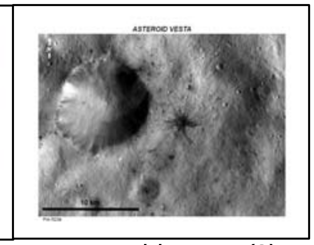

Data Collection (Earth)


Data Collection (Planetary)


Crater Image Metadata







Images of: Earth (8) Mars (8) Earth's Moon (8) Asteroid Vesta (8)

1. GETTING ORGANIZED: This step in the process of science will give students experience collecting and compiling data. It is strongly recommended that you have your students create a spreadsheet (Excel or Google spreadsheet for example) to input their data. This will allow them to more easily sort the data, which will be useful as they later display their data. If you have access to computers, assign 1-2 students within the group to take on the responsibility of compiling the data from the rest of the group into the spreadsheet. Periodically, as students within the group collect and log data for a couple of impact craters on a hard copy data collection sheet, have them provide that data to the spreadsheet team members. While students input data into the spreadsheet, the other students can continue to collect and log additional data (on additional hard copy log sheets). This will allow all group members to make progress with the data collection with the end result being a complete master data table in both hard copy and spreadsheet format.

As this investigation focuses on comparing craters on Earth to craters on other worlds, one way to approach this is to have different groups of students focus on different planetary worlds. If you have 6 groups of students, 1 group can focus on Earth, while the others focus on Earth's Moon, Mars, Vesta, Mercury, and/or Venus. If you have more than 6 groups of students, assign multiple groups to the same planetary body. Alternatively, you may want to assign multiple groups to the same planetary world. Again, choose which worlds you want your students to investigate. They do not have to look at all planetary worlds included in this activity.

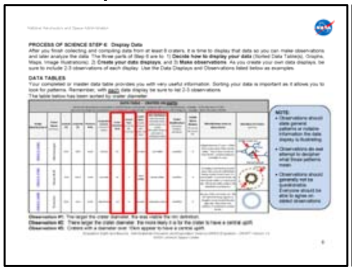
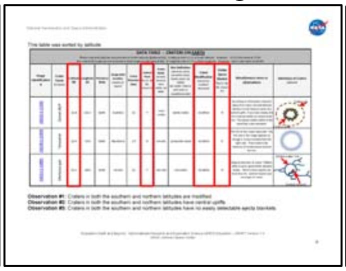
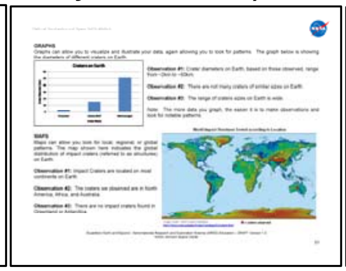
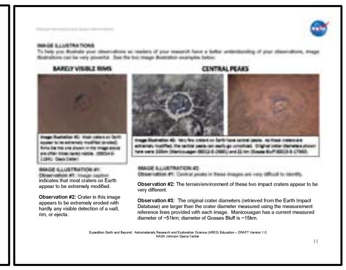
2. COLLECTING DATA:

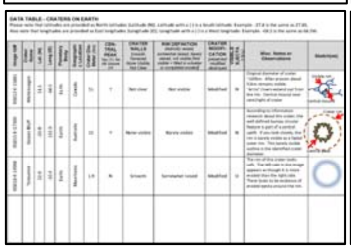
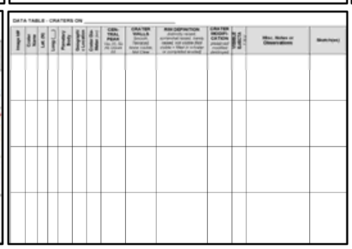
- Provide students with the Crater Image Metadata Handout and images they will use to collect and compile data of the planetary world they will focus on.
- Provide hard copy data collection sheets to students so they can log data as they make observations.
- Students should aim to collect data on at least 8 different impact craters found in images of their planetary world.
- Make sure students log data consistently.

STEP 6: DISPLAY DATA (~1 class period)

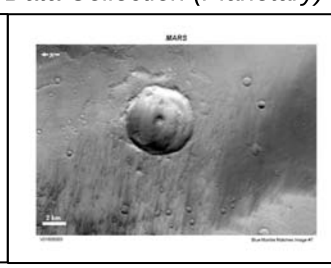
Materials Needed for Step 6:

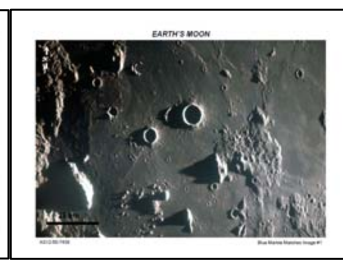
- *Student Guide pages 8-11*
- *Hard copy (and/or spreadsheet of) data collection sheets (Earth or other planetary world)*
- *Images of impact craters (~8 images per planetary body)*
  (Not shown below: Thumbnail image of Mercury and Venus)

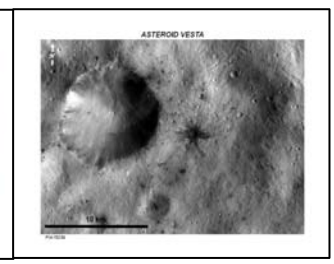





Data Collection (Earth) *Data Collection (Planetary)*







Images of: Earth (8) *Mars (8)* *Earth's Moon (8)* *Asteroid Vesta (8)*

Depending on the level of your students and how much guidance you feel they need, have them read over the PROCESS OF SCIENCE STEP 6: Data Display section in the *Student Guide* (pages 8 – 11). Each group will need to:

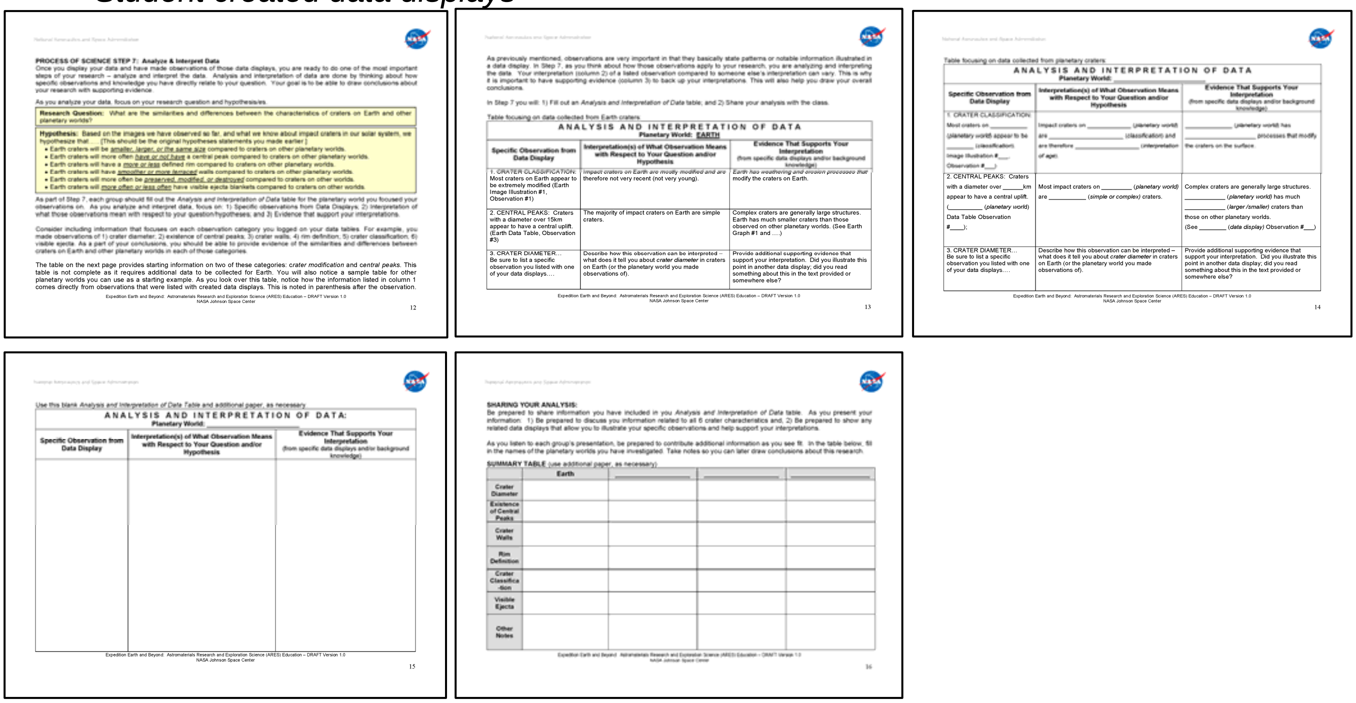
- ***Decide how to display their data*:** There are 4 suggested data display options: 1) Sorted data tables, 2) Graphs; 3) Maps; 4) Image Illustrations.
- ***Create those data displays:*** Students within each group should divide up how they want to organize themselves to create those data displays.
- ***Make observations of each data display:*** As students finish any data display, they should list 2-3 observations of what that data are showing.

Students should use the examples provided in the *Student Guide* for guidance and/or data display options they may want to consider.

STEP 7: ANALYZE & INTERPRET DATA (~2 class periods)

Materials Needed for Step 7:

- *Student Guide pages 12-16*
- *Student created data displays*



Step 7, the analysis and interpretation of data, is one of the most important aspects of any research investigation. It can also be a challenging step for many students.

For starters, students should be sure to revisit the research question and the original hypotheses they listed in Step 4 of this process. As they analyze the data, their analysis should focus and directly relate to these aspects of their research. To complete this step, students will 1)Fill out an *Analysis and Interpretation of Data* table and 2)Share their analysis with the class.

1. COMPLETING THE ANALYSIS & INTERPRETATION OF DATA TABLE: The *Analysis & Interpretation of Data* Table provided should help students organize their thoughts. As students analyze and interpret data, it is important that they focus on:

- ***Column 1: Specific observations from Data Displays:*** Students should list previously written observations (from Step 6) that they feel are specifically relevant to the research question/hypotheses. To help reinforce that they are listing previously made observations, the sample information listed includes the data display name and observation # in parenthesis after each listed observation in column 1.
- ***Column 2: Interpretation of What Observation Means with Respect to Your Question and/or Hypothesis:*** Students should state or explain how they think the listed observation connects and applies to their question and/or hypotheses.

These first two columns are similar to *IF….THEN….* statements. ***IF****….name a specific observation….****THAN****….describe what that might mean with respect to the research.*

- ***Column 3: Evidence That Support Your Interpretation:*** Students should list additional evidence that supports their interpretation. Supporting evidence could be from another data display they created and/or background knowledge they may have learned that supports this interpretation.

To help students complete this table, it is suggested that they aim to include information related to each of the crater characteristics they examined. This includes: 1) Crater diameter, 2) existence of central peaks, 3) crater walls, 4) rim definition, 5) crater classification, and 6) visible ejecta.

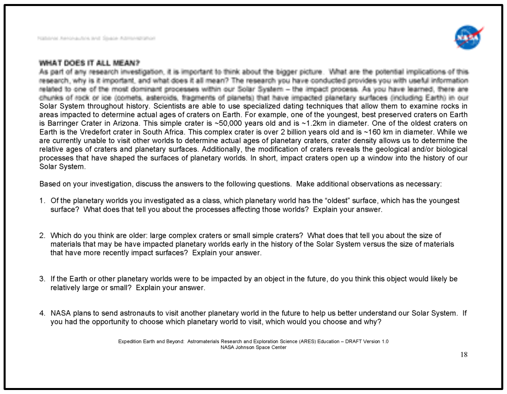
2. SHARING FINDINGS
As students will have put together data and information from different planetary worlds, students should briefly present this information to the rest of the class. Each group of students should be prepared to share information they have included in the *Analysis and Interpretation of Data* table. As students present their information they should:

1. Be prepared to discuss information related to all 6 crater characteristics.
2. Be prepared to show any related data displays that allow them to illustrate their specific observations and help support their interpretations.

As students listen to each group's presentation, they should contribute additional information as they see fit. Students should also take notes as other groups present. This will help them draw conclusions. A summary table is provided on page 16 of the *Student Guide.*

STEP 8: DRAW CONCLUSIONS (~1 class period)
Materials Needed for Step 8:

- *Student Guide page 17 and 18*



National Aeronautics and Space Administration

WHAT DOES IT ALL MEAN?
As part of any research investigation, it is important to think about the bigger picture. What are the potential implications of this research, why is it important, and what does it all mean? The research you have conducted provides you with useful information related to one of the most dominant processes within our Solar System – the impact process. As you have learned, there are chunks of rock or ice (comets, asteroids, fragments of planets) that have impacted planetary surfaces (including Earth) in our Solar System throughout history. Scientists are able to use specialized dating techniques that allow them to examine rocks in areas impacted to determine actual ages of craters on Earth. For example, one of the youngest, best preserved craters on Earth is Barringer Crater in Arizona. This simple crater is ~50,000 years old and is ~1.2km in diameter. One of the oldest craters on Earth is the Vredefort crater in South Africa. This complex crater is over 2 billion years old and is ~160 km in diameter. While we are currently unable to visit other worlds to determine actual ages of planetary craters, crater density allows us to determine the relative ages of craters and planetary surfaces. Additionally, the modification of craters reveals the geological and/or biological processes that have shaped the surfaces of planetary worlds. In short, impact craters open up a window into the history of our Solar System.

Based on your investigation, discuss the answers to the following questions. Make additional observations as necessary:

1. Of the planetary worlds you investigated as a class, which planetary world has the "oldest" surface, which has the youngest surface? What does that tell you about the processes affecting those worlds? Explain your answer.
2. Which do you think are older: large complex craters or small simple craters? What does that tell you about the size of materials that may be have impacted planetary worlds early in the history of the Solar System versus the size of materials that have more recently impact surfaces? Explain your answer.
3. If the Earth or other planetary worlds were to be impacted by an object in the future, do you think this object would likely be relatively large or small? Explain your answer.
4. NASA plans to send astronauts to visit another planetary world in the future to help us better understand our Solar System. If you had the opportunity to choose which planetary world to visit, which would you choose and why?

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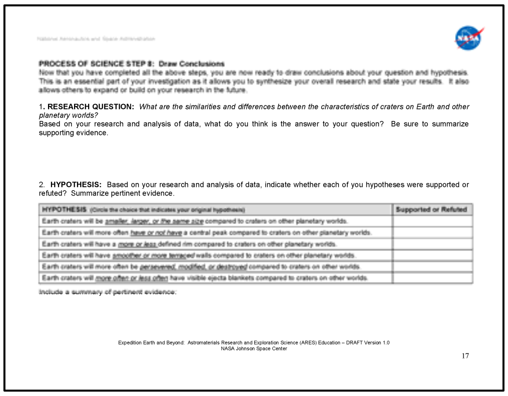

National Aeronautics and Space Administration

PROCESS OF SCIENCE STEP 8: Draw Conclusions
Now that you have completed all the above steps, you are now ready to draw conclusions about your question and hypothesis. This is an essential part of your investigation as it allows you to synthesize your overall research and state your results. It also allows others to expand or build on your research in the future.

1. **RESEARCH QUESTION:** *What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?*
Based on your research and analysis of data, what do you think is the answer to your question? Be sure to summarize supporting evidence.

2. **HYPOTHESIS:** Based on your research and analysis of data, indicate whether each of you hypotheses were supported or refuted? Summarize pertinent evidence.

HYPOTHESIS (Circle the choice that indicates your original hypothesis)	**Supported or Refuted**
Earth craters will be smaller, larger, or the same size compared to craters on other planetary worlds.	
Earth craters will more often have or not have a central peak compared to craters on other planetary worlds.	
Earth craters will have a more or less defined rim compared to craters on other planetary worlds.	
Earth craters will have smoother or more terraced walls compared to craters on other planetary worlds.	
Earth craters will more often be perservered, modified, or destroyed compared to craters on other worlds.	
Earth craters will more often or less often have visible ejecta blankets compared to craters on other worlds.	

Include a summary of pertinent evidence:

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In Step 8 of the process of science, students are now ready to 1) draw conclusions about their research and originally stated hypotheses and 2) think about the potential implications of their research.

A. DRAW CONCLUSIONS: Based on information presented and shared, students should be able to provide an answer to the research question as well as indicate whether their initial hypotheses were supported or refuted. Students should summarize pertinent evidence as part of their answers.

B. WHAT DOES IT ALL MEAN? It is important for students to now think about the potential implications of this research, why it is important, and what it all means. Have students read over the information on page 18 of the *Student Guide* and discuss the answers to the questions posed in their groups. After student groups have had the opportunity to discuss the questions, discuss as a class.

1. Of the planetary worlds you investigated as a class, which planetary world has the "oldest" surface, which has the youngest surface? What does that tell you about the processes affecting those worlds? Explain your answer.

Oldest Surface: *Potential answers for the "oldest" surface are Earth's Moon or Mercury. Using what they have learned about crater density, images of these worlds include numerous craters, which is why their surfaces would be considered older than Earth, Mars, Venus, or Vesta.*

Youngest Surface: *The answer to this should be Earth. Earth appears to have fewer craters than all other planetary surfaces and most of the craters on Earth have been eroded by active processes.*

What does this tell you about the processes affecting these worlds: *Students should discuss evidence of geologic (or biological) processes and consider "when" those processes may have occurred. For example, Earth has active geological processes that are constantly changing the surface of our planet today. Mars appears to have evidence of water, wind, possibly volcanic processes, some of which may be occurring "today". Images of Earth's Moon provide evidence of volcanic processes which likely occurred early in its history. This is observed by the larger craters on the Moon that have been filled in most likely by lava. (Volcanic and Impact processes have been the two dominant processes that have shaped the surface of the Moon.) Younger craters on the Moon are much more preserved and do not show evidence of being filled in by lava or modified by any active processes. This supports that volcanic activity occurred early in the Moon's history and that there are no active processes that have changed these smaller younger craters since they formed. The craters on Mercury appear to be similar to those on the Moon although it does not appear as though they have been modified as much by volcanic activity. Images of Vesta show evidence of some sort of active processes affecting the surface and modifying craters although it is uncertain what those processes may be. Most of the images of craters on Venus clearly show visible ejecta blankets and central peaks. Images show evidence of erosion, though it is not clear what those processes may be, although Venus is thought to be influenced by volcanic processes.*

2. Which do you think are older: large complex craters or small simple craters? What does that tell you about the size of materials that may be have impacted planetary worlds early in the history of the Solar System versus the size of materials that have more recently impact surfaces? Explain your answer.

Large complex craters are older than small simple craters. This tells us that early in the history of the Solar System there were larger pieces of materials impacting planetary surfaces compared to what we see today. As the Solar System evolved, fewer and fewer large fragments were "floating around" in the Solar System as they potentially coalesced and became part of the terrestrial worlds we see today. Younger craters seen on planetary surfaces today are generally smaller than those that formed early in the planet's history.

3. If the Earth or other planetary worlds were to be impacted by an object in the future, do you think this object would likely be relatively large or small? Explain your answer.

Based on the previous question, students should answer this indicating that objects would be relatively small. We do see meteors in our night sky, which are small grains of dust attempting to make it through our atmosphere before they burn up. Students may reference other newsworthy events such as the object that entered Earth's atmosphere in Russia (Spring 2013). Although this impactor caused some damage in the local area, this object was not thought to be a large object. (The object itself was not recovered.) There are scientists who track the orbits of what are called Near Earth Objects (NEOs). Some of these objects may come close to the Earth in the future but assure students that scientists have no evidence to believe Earth is on a collision course with any potentially hazardous objects. Students may think of or ask about the impact that is thought to have wiped out the dinosaurs. Assure students that impacts such as this are uncommon and with instruments and detection capabilities scientists have today, we would be able to detect any incoming hazardous object with enough time to consider how to help mitigate any danger.

4. NASA plans to send astronauts to visit another planetary world in the future to help us better understand our Solar System. If you had the opportunity to choose which planetary world to visit, which would you choose and why?

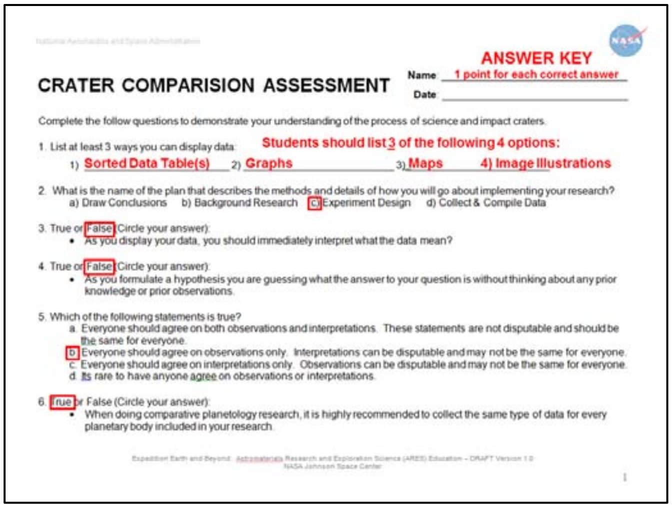
Student answers will vary.

PART 4: Evaluate (Crater Comparison Assessment) (~20-30 minutes)

The *Crater Comparison Assessment* can be used to evaluate student skills after the completion of this activity. This assessment focuses on the process of science and information related to impact craters. Each question and correct answer is worth 1 point. The grading rubric is as follows:

- 18-20 points: A
- 15-17 points: B
- 12-14 points: C
- 9-11 points: D
- Below 9 points: F

Answer key is below: (1 point per correct answer)



ANSWER KEY

CRATER COMPARISION ASSESSMENT Name 1 point for each correct answer Date

Complete the follow questions to demonstrate your understanding of the process of science and impact craters.

1. List at least 3 ways you can display data: Students should list 3 of the following 4 options:
   1) Sorted Data Table(s) 2) Graphs 3) Maps 4) Image Illustrations
2. What is the name of the plan that describes the methods and details of how you will go about implementing your research?
   a) Draw Conclusions b) Background Research [c)] Experiment Design d) Collect & Compile Data
3. True or [False] (Circle your answer):
   - As you display your data, you should immediately interpret what the data mean?
4. True or [False] (Circle your answer):
   - As you formulate a hypothesis you are guessing what the answer to your question is without thinking about any prior knowledge or prior observations.
5. Which of the following statements is true?
   a. Everyone should agree on both observations and interpretations. These statements are not disputable and should be the same for everyone.
   [b.] Everyone should agree on observations only. Interpretations can be disputable and may not be the same for everyone.
   c. Everyone should agree on interpretations only. Observations can be disputable and may not be the same for everyone.
   d. Its rare to have anyone agree on observations or interpretations.
6. [True] or False (Circle your answer):
   - When doing comparative planetology research, it is highly recommended to collect the same type of data for every planetary body included in your research.

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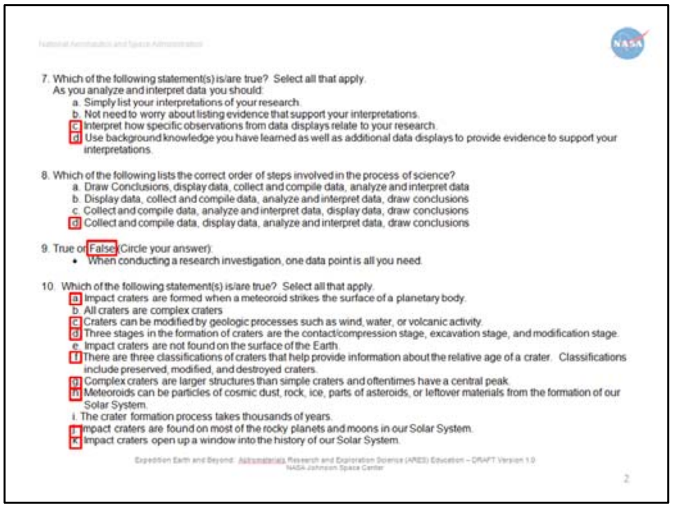

7. Which of the following statement(s) is/are true? Select all that apply.
   As you analyze and interpret data you should:
   a. Simply list your interpretations of your research.
   b. Not need to worry about listing evidence that support your interpretations.
   [c.] Interpret how specific observations from data displays relate to your research.
   [d.] Use background knowledge you have learned as well as additional data displays to provide evidence to support your interpretations.
8. Which of the following lists the correct order of steps involved in the process of science?
   a. Draw Conclusions, display data, collect and compile data, analyze and interpret data
   b. Display data, collect and compile data, analyze and interpret data, draw conclusions
   c. Collect and compile data, analyze and interpret data, display data, draw conclusions
   [d.] Collect and compile data, display data, analyze and interpret data, draw conclusions
9. True or [False] (Circle your answer):
   - When conducting a research investigation, one data point is all you need.
10. Which of the following statement(s) is/are true? Select all that apply.
    [a.] Impact craters are formed when a meteoroid strikes the surface of a planetary body.
    b. All craters are complex craters
    [c.] Craters can be modified by geologic processes such as wind, water, or volcanic activity.
    [d.] Three stages in the formation of craters are the contact/compression stage, excavation stage, and modification stage.
    e. Impact craters are not found on the surface of the Earth.
    [f.] There are three classifications of craters that help provide information about the relative age of a crater. Classifications include preserved, modified, and destroyed craters.
    [g.] Complex craters are larger structures than simple craters and oftentimes have a central peak.
    [h.] Meteoroids can be particles of cosmic dust, rock, ice, parts of asteroids, or leftover materials from the formation of our Solar System.
    i. The crater formation process takes thousands of years.
    [j.] Impact craters are found on most of the rocky planets and moons in our Solar System.
    [k.] Impact craters open up a window into the history of our Solar System.

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1. Students should list 3 of the following options: 1) Sorted Data Table(s), 2) Graphs, 3) Maps, 4) Image Illustrations

2. C	3. False	4. False	5. B	6. True
7. C & D	8. D	9. False	10. A, C, D, F, G, H, J, K	

SUGGESTED OVERALL GRADING RUBRIC: As this activity will have students working in groups to complete the mini-research investigation, the following rubric can be used as the grading rubric for each step of the process of science (NOTE: Steps 1-4 are not called out separately as those steps are accomplished as a guided introduction completed as a class).

Share this grading rubric with students at the start of the activity so they will understand how they will be graded on this activity.

90-100%:

- **Engagement (E):** Clearly engaged in all parts of this step(s) of the process of science. Excellent participation in group and/or class discussions.
- **Task Completion (TC):** Demonstrated a complete understanding of this aspect of the process of science.

80 – 89%:

- **Engagement (E):** Engaged in most parts of this step(s) of the process of science. Good participation in group and/or class discussions.
- **Task Completion (TC):** Demonstrated a good understanding of this aspect of the process of science.

70 – 79%:

- **Engagement (E):** Somewhat engaged in most parts of this step(s) of the process of science. Limited participation in group and/or class discussions.
- **Task Completion (TC):** Demonstrated limited understanding of this aspect of the process of science.

60 – 69%:

- **Engagement (E):** Poorly engaged in all parts of this step(s) of the process of science. Poor participation in group and/or class discussions.
- **Task Completion (TC):** Demonstrated a poor understanding of this aspect of the process of science.

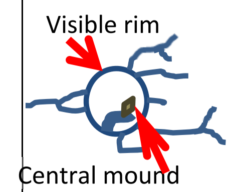
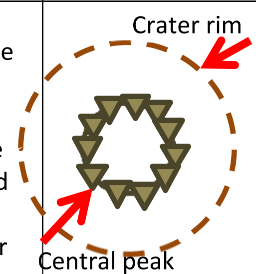
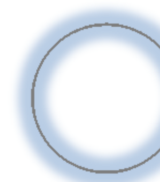
Below 60%:

- **Engagement (E):** Little to no engagement in this step(s) of the process of science. Little to no participation in group and/or class discussions.
- **Task Completion (TC):** Demonstrated little to no understanding of this aspect of the process of science.

Student Name:												
	Steps 1–4		**Step 5**		**Step 6**		**Step 7**		**Step 8**		**Potential Implications**	
	E	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**	**E**	**TC**
90–100%												
80 – 89%												
70-79%												
60-69%												
Below 60%												

DATA TABLE - CRATERS ON EARTH

Please note that latitudes are provided as North latitudes [Latitude (N)]. Latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. Longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Id#	**Crater Name**	**Lat. (N)**	**Long (E)**	**Planetary Body**	**Geographic Location**	**Crater Dia-Meter** *(km)*	**CEN-TRAL PEAK** *Yes (Y), No (N) Unsure (U)*	**CRATER WALLS** *Smooth, Terraced, None Visible, Not Clear*	**RIM DEFINITION** *distinctly raised, somewhat raised, barely raised, not visible [Not visible = filled in w/water or completed eroded]*	**CRATER MODIFI-CATION** *preserved modified destroyed*	**VISIBLE EJECTA** *Y,N,U*	**Misc. Notes or Observations**	**Sketch(es)**
ISS012-E-15881	Manicouagan	51.5	-68.5	Earth	Canada	51	Y	Not clear	Not visible	Modified	N	Original diameter of crater ~100km. After erosion about 51km remains visible. "Arms"/rivers extend out from the rim. Central mound near cent/right of crater	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	15	Y	None visible	Barely visible	Modified	N	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	N	Smooth	Somewhat raised	Modified	U	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	

DATA TABLE - CRATERS ON EARTH

Please note that latitudes are provided as North latitudes [Latitude (N)]. Latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. Longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Id#	**Crater Name**	**Lat. (N)**	**Long (E)**	**Planetary Body**	**Geographic Location**	**Crater Dia-Meter** *(km)*	**CEN-TRAL PEAK** *Yes (Y), No (N) Unsure (U)*	**CRATER WALLS** *Smooth, Terraced, None Visible, Not Clear*	**RIM DEFINITION** *distinctly raised, somewhat raised, barely raised, not visible [Not visible = filled in w/water or completed eroded]*	**CRATER MODIFI-CATION** *preserved modified destroyed*	**VISIBLE EJECTA** *Y,N,U*	**Misc. Notes or Observations**	**Sketch(es)**

DATA TABLE - CRATERS ON ___________________________________

Image Id#	Crater Name	Lat. (N)	Long (___)	Planetary Body	Geographic Location	Crater Dia-Meter *(km)*	**CEN-TRAL PEAK** *Yes (Y), No (N) Unsure (U)*	**CRATER WALLS** *Smooth, Terraced, None Visible, Not Clear*	**RIM DEFINITION** *distinctly raised, somewhat raised, barely raised, not visible [Not visible = filled in w/water or completed eroded]*	**CRATER MODIFI-CATION** *preserved modified destroyed*	**VISIBLE EJECTA** *Y,N,U*	**Misc. Notes or Observations**	**Sketch(es)**

CRATER IMAGE METADATA

EARTH IMAGES

BMM Image #	Image ID#	LAT.	LONG.	Camera	Lens Focal Length	Date Acquired	Country or Geographic Region	Crater Name
1	ISS006-E-16068	27.8S	16.4E	E4: Kodak DCS760C	400mm	12/28/2002	Namibia	Roter Kamm
2	ISS012-E-15881	51.5N	68.5W	E4: Kodak DCS760C	50mm	1/24/2006	Canada	Manicouagan
3	ISS014-E-11841	24.4N	24.4E	E4: Kodak DCS760C	400mm	1/13/2007	Libya	Oasis
4	ISS014-E-15775	35N	111W	E4: Kodak DCS760C	400mm	3/1/2007	United States	Barringer
5	ISS014-E-19496	29N	7.6W	E4: Kodak DCS760C	800mm	4/16/2007	Algeria	Ouarkziz
6	ISS015-E-17360	23.9S	132.3E	E4: Kodak DCS760C	400mm	7/13/2007	Australia	Gosses Bluff
7	ISS018-E-14908	22.9N	10.4W	Nikon D2X	800mm	12/20/2008	Mauritania	Tenoumer
8	ISS018-E-23713	20N	76.5E	Nikon D2X	800mm	1/28/2009	India	Lonar

MARS IMAGES

BMM Image #	Image ID#	LAT.	LONG.	Camera	*Pixel Resolu-tion	*Date Acquired	*Geographic Region	*Crater Name
2	V05055010	31.3N	19.1E	THEMIS VIS	18 m/px	2/3/2003	Northern Arabia	
5	V11030007	20.7N	125.9E	THEMIS VIS	18 m/px	6/9/2004	Elysium	
7	V01605003	14.7S	174.7E	THEMIS VIS	18m/px	4/25/2002	Gusev Crater	
10 (2)	V18317011	0.3N	155.5E	THEMIS VIS	18 m/px			
12 (4)	MOC2-1225a	24S	33W	Mars Obiter Camera			Eberswalde	
13 (5)	ESP_013954_1780	2.1S	354.5E	HiRise	25 cm/pixel	7/18/2009	Meridiani Planum	Victoria
14 (6)	V01695013	0.04N	71.9E	THEMIS VIS	18 m/px	6/6/2002	Syrtis Major	
16 (8)	Viking Image	42S	92W	Viking orbiter				

*Some information not available

CRATER IMAGE METADATA

EARTH'S MOON

BMM Image #	Image ID#	LAT.	LONG.	Camera	*Pixel Resolu-tion	*Date Acquired	*Geographic Region	Crater Name
1	AS12-50-7438	2.5S	14W	Hasselblad	70mm			Gambart
2	AS12_h_50_7431	4S	6.5E	Hasselblad	70mm	April 1972		Herschel
3	AS16-0692	11S	26E	Metric Mapping				Theophilus
4	L05-H105	25N	2.95E	Medium Resolution Camera		8/14/1967		Hadley
5	AS15-1010	26N	19.5W	Metric Mapping		1971		Lambert
6	AS15-M-0424	25.5N	10W	Metric Mapping		7/31/1971		Archimedes
7	AS15-2606	24N	47W	Metric Mapping	76mm	Aug.1971		Prinz (Center) Aristarchus (bright crater/upper right)
8	AS15-2083	28.5N	46W	Metric Mapping	3 inch	1971		Krieger

VESTA

BMM Image #	Image ID#	*LAT.	*LONG.	Camera	*Pixel Resolu-tion	*Date Acquired	*Geographic Region	*Crater Name
	PIA15239			Framing Camera		1/8/2012	Sextila Quadrangle	Laelia
	PIA15598			Framing Camera	65m/px	10/2/2011		Sextilla (upper right), Laelia (lower left)
	PIA15649			Framing Camera				Octavia
	PIA16491			Framing Camera		2/7/2012		Fonteia
	PIA16489			Framing Camera		1/11/2012		Cornelia
	PIA15235			Framing Camera		10/25/2011		Canuleia
	PIA14829			Framing Camera	63m/px	10/2/2011		
	PIA15324			Framing Camera	250m/px	8/29/2011	Pinaria Quadrangle	

*Some information not available

CRATER IMAGE METADATA

MERCURY								
BMM Image #	**Image ID#**	***LAT.**	***LONG.**	**Camera**	***Pixel Resolu-tion**	**Date Acquired**	***Geographic Region**	***Crater Name**
1	PIA12163			Narrow Angle Camera	280 m/px	10/6/2008		
2	PIA12068			Narrow Angle Camera	240 m/px	10/6/2008		
3	PIA12049	33.2S	271.8W	Narrow Angle Camera		10/6/2008		Rembrandt basin
4	PIA11355	11S	31.5W	Narrow Angle Camera	530 m/px	10/6/2008		Kuiper
5	PIA12368			Narrow Angle Camera		9/29/2009		
6	PIA12054			Narrow Angle Camera	420 m/px	10/6/2008		
7	PIA12370			Narrow Angle Camera		9/29/2009		
8	PIA12116	15.2N	48.1W	Narrow Angle Camera	250 m/px	10/6/2008		Lermontov

*Some information not available

VENUS								
BMM Image #	**Image ID#**	**LAT.**	**LONG.**	**Camera**	***Pixel Resolu-tion**	***Date Acquired**	***Geographic Region**	***Crater Name**
4	PIA00086	27S	339W	Imaging Radar		Sept. 1990		
6	PIA00466	15N	5E	Imaging Radar				
7	PIA00239	20.3N	331.8E	Imaging Radar				

*Some information not available

CRATER COMPARISION ASSESSMENT

Name: ______________________________

Date: ______________________________

Complete the follow questions to demonstrate your understanding of the process of science and impact craters.

1. List at least 3 ways you can display data:

   1) ________________________ 2) ________________________ 3)________________________

2. What is the name of the plan that describes the methods and details of how you will go about implementing your research?

   a) Draw Conclusions b) Background Research c) Experiment Design d) Collect & Compile Data

3. True or False (Circle your answer):
   - As you display your data, you should immediately interpret what the data mean?

4. True or False (Circle your answer):
   - As you formulate a hypothesis you are guessing what the answer to your question is without thinking about any prior knowledge or prior observations.

5. Which of the following statements is true?

   a. Everyone should agree on both observations and interpretations. These statements are not disputable and should be the same for everyone.
   b. Everyone should agree on observations only. Interpretations can be disputable and may not be the same for everyone.
   c. Everyone should agree on interpretations only. Observations can be disputable and may not be the same for everyone.
   d. Its rare to have anyone agree on observations or interpretations.

6. True or False (Circle your answer):
   - When doing comparative planetology research, it is highly recommended to collect the same type of data for every planetary body included in your research.

7. Which of the following statement(s) is/are true? Select all that apply.
   As you analyze and interpret data you should:
    a. Simply list your interpretations of your research.
    b. Not need to worry about listing evidence that support your interpretations.
    c. Interpret how specific observations from data displays relate to your research.
    d. Use background knowledge you have learned as well as additional data displays to provide evidence to support your interpretations.

8. Which of the following lists the correct order of steps involved in the process of science?
    a. Draw Conclusions, display data, collect and compile data, analyze and interpret data
    b. Display data, collect and compile data, analyze and interpret data, draw conclusions
    c. Collect and compile data, analyze and interpret data, display data, draw conclusions
    d. Collect and compile data, display data, analyze and interpret data, draw conclusions

9. True or False (Circle your answer):
    - When conducting a research investigation, one data point is all you need.

10. Which of the following statement(s) is/are true? Select all that apply.
    a. Impact craters are formed when a meteoroid strikes the surface of a planetary body.
    b. All craters are complex craters
    c. Craters can be modified by geologic processes such as wind, water, or volcanic activity.
    d. Three stages in the formation of craters are the contact/compression stage, excavation stage, and modification stage.
    e. Impact craters are not found on the surface of the Earth.
    f. There are three classifications of craters that help provide information about the relative age of a crater. Classifications include preserved, modified, and destroyed craters.
    g. Complex craters are larger structures than simple craters and oftentimes have a central peak.
    h. Meteoroids can be particles of cosmic dust, rock, ice, parts of asteroids, or leftover materials from the formation of our Solar System.
    i. The crater formation process takes thousands of years.
    j. Impact craters are found on most of the rocky planets and moons in our Solar System.
    k. Impact craters open up a window into the history of our Solar System.